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PRINCETON UNIVERSITY

DEPARTMENT OF AERONAUTICAL ENGINEERING

DESIGN STUDY OF A MODIFIED HIGH LIFT AND LATERAL
CONTROL SYSTEM FOR THE L-21 AIRPLANE

Report #422 July, 1958

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OFFICE OF NAVAL RESEARCH DEPARTMENT OF THE NAVY
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12. Abstract:

Consideration is given to spoiler type lateral controls as a means of utilizing full span flaps. An air jet spoiler (Ref. 2&3) is described which eliminates some of the response problems associated with mechanical spoilers, as well as a high lift system utilizing this device in conjunction with moderate BLC equipment. Preliminary calculations are carried out for this system applied to the L-21 (PA-18) aircraft. For boundary layer blowing over the inboard flap ($C_{\mu_{BLC}} = .03$) and simultaneous application of full spoiler ($Pb/2v = .07$), the power supply described in Ref. 5 is found to be adequate as an air source. The modified aircraft has a calculated $C_{L_{max}}$ of 2.98 under power using the stock engine, and requires additional longitudinal trim during landing sufficient to change the effective incidence of the tail -11.5°.

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Foreword

The research reported herein was conducted by Princeton University under the direction of the Office of Naval Research, Department of the Navy, in cooperation with the Office of Chief of Transportation, Department of the Army. This report contains the final results of Phase VI of the following six phases of the overall research program:

I Basic Lateral Control Characteristicd of the L-21 Airplane

II Jet Spoiler Performance of the L-21 Airplane

III Pressure Distribution Investigation of a Jet Spoiler on the L-21 Airplane

IV Two-Dimensional Test with a Jet Spoiler

V Investigation of Jet Spoiler Lateral Controls on a Moderately Thick Wing of High Aspect Ratio

VI Design Study of a Modified High Lift and Lateral Control System for the L-21 Airplane

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LIST OF SYMBOLS USED

C_L	Wing lift coefficient = $\frac{L}{q_o S_w}$	
V_s	Spoiler jet velocity	ft/sec
V_{BLC}	Boundary layer control jet velocity	ft/sec
V_o	Free stream velocity	ft/sec
δ_s	Spoiler jet width	ft.
δ_{BLC}	BLC jet width	ft.
ρ	Density	slugs/ft^3
q_o	Free stream dynamic pressure	lbs/ft^2
C_μ	Momentum coefficient = $\frac{\rho V^2 \delta}{q_o S_w}$	
Q	Volume flow	ft^3/sec
C_Q	Volume flow coefficient = $\frac{Q}{V_o S_w}$	
S_w	Wing area	ft^2
b	Wing span	
$\bar{c}$	Mean aerodynamic chord	ft.
c_f	Flap chord	ft.
$\bar{c}$	Mean chord over blowing slot	ft.
AR	Aspect ratio	
W	Aircraft weight	lbs.
$\frac{Pb}{2V}$	Wing tip helix angle in roll	radians
ΔP	Pressure differential across blowing slot	lbs/ft^2
C	Discharge coefficient of slot	$\left(\frac{ft^2}{sec\ lb}\right)^{1/2}$
α	Angle of attack	degrees
α_{OL}	Angle of zero lift	degrees
a_w	Wing lift curve slope	degrees^{-1}

a_t	Tail lift curve slope	degrees^{-1}
x_{ac}	Location of wing aerodynamic center, $\%\bar{c}$	
x_{cg}	Location of aircraft center of gravity, $\%\bar{c}$	
$C_{M_{ac}}$	Aircraft pitching moment about aerodynamic center	
Δi_t	Increment in horizontal tail incidence	degrees
$\Delta \delta_e$	Increment in elevator angle	degrees
ϵ	Downwash at tail	degrees
C_l	Rolling moment coefficient	
C_{l_p}	Coefficient of damping in roll	

I. Introduction

Due to the extreme demands now placed on the primary lifting surfaces of aircraft in the landing configuration, considerable emphasis is directed toward efficient utilization of wing planform so that the maximum lift will enable sufficiently low landing speeds. The high wing loading demanded by drag considerations at the higher velocities has forced the designer to investigate the possibilities of many new means of lift augmentation. If we consider a "conventional" aircraft configuration, that is, an aircraft having a lifting surface of moderate aspect ratio, horizontal and vertical stabilizer, and no lift contributions from the thrust of the engine or its slipstream, it is clear that there are two general groups of devices which increase the maximum lift coefficient of a wing of given planform:

1) Those which alter the effective angle of attack of the wing, such as common flaps, as well as the more recent jet flap;
2) Those which delay the separation of the flow from the upper rear surface of the wing, such as drooped leading edges, leading edge slats, and boundary layer suction and blowing.

Neglecting weight and structural (as well as power) penalties, these devices may be employed as required as long as the more stringent demands of stability and control can be met. Usually this will mean the utilization of a large portion of the wing trailing edge for the aileron, with the result that most efforts toward higher maximum lift coefficients have begun with the reducing of aileron span to a minimum, or doing away with it entirely and employing one of the many types of spoiler configurations. Since the use of the latter type of control exposes the entire wing span to high lift devices, this report will deal with the advantages to be gained by the use of spoiler type controls, from the standpoint of improved low speed performance. In particular, the relative merits of a comparatively new type of spoiler are presented.

Recent tests of an air jet spoiler (Refs. 2 and 3) have shown that control characteristics similar to that of conventional spoilers can be obtained with relatively low volume flow requirements. Since this device offers some improvements over mechanical spoilers, a critical examination of its practicability is quite pertinent to this study; and since the use of auxiliary power for boundary layer control is of current interest, the possibility of an integrated jet control - BLC system must be examined. Several characteristics of these controls will be dealt with:

1) The effectiveness of the control over the angle of attack range and velocity range for which it is to be used, including the response characteristics,
2) The high lift devices which become practical from its use, and,
3) The weight and power penalties involved, as well as the mechanical complexity of the arrangement.

In evaluating the improved low speed performance obtainable by these devices, emphasis is placed, within the framework of this study, on optimization of the maximum lift coefficient of the aircraft. A more detailed analysis must involve drag increments which arise, and their effect upon power requirements at low speeds. Calculations are carried out for the L-21 aircraft (PA 18), an Army liaison plane, but are applicable to aircraft having much higher wing loadings (where the maximum lift coefficient has a more appreciable effect upon landing speed). A layout of this aircraft is given in Figure 5.

II. Discussion

a. Control characteristics of conventional and air jet spoilers

Figures 1 and 2 show typical variation of rolling moment coefficients for several types of mechanical spoilers. It is obvious that the non-linearity in the action of these spoilers will be highly undesirable during the landing maneuver. The effectiveness of the spoiler will usually increase as it is moved rearward, and as the angle of attack is increased, though there is a slight fall-off at high angles of attack. The yawing moment is in most cases favorable. Of interest here is the considerable aerodynamic time lag in the action of these devices, from .1 to 1 second, approximately, depending on the particular design (Ref. 12). The air jet controls shown in Fig. 3 are invariant with angle of attack up to 12° (Ref. 2), and display no ineffectiveness near the origin. The abscissa in this case is the non-dimensionalized momentum flux of the jet, C_μ, which is related to the power requirement of the jet spoiler and is dealt with below. The effectiveness of a spoiler is roughly proportional to its span provided it represents a small fraction of the wing span. It is usually found that the rolling moment coefficient increases with the deflection of a flap situated behind the spoiler, although the increase will usually diminish with increasing angle of attack.

The references cited show that, in most cases, adequate lateral control can be maintained for aircraft having full span flaps by the use of a spoiler-type device, although its exact design must be carefully fitted to the particular wing. The problem of non-linear response to control deflection appears to be greatly alleviated by the use of an airjet spoiler, but the aerodynamic lag for this type of spoiler may not be any less than for the mechanical spoiler.

As far as is known this has not been measured. The effectiveness of these devices can be expected to be increased by any device which delays the stalling of the wing by energizing the flow near its surface.

b. <u>Use of high lift devices in conjunction with a spoiler</u>

If the aileron of a conventional aircraft is replaced by an upper surface spoiler, the only practical high lift device which is subsequently available is a conventional flap in place of the aileron. Since this will be near the tip of the wing, $\Delta\alpha_{o.L.}$, the increase in the angle of zero lift of the wing, will be smaller than for an equivalent flap near the root. This increase can be predicted with sufficient accuracy by the methods of Ref. 8. The use of tip plates to suppress further spanwise flow will increase considerably the contribution from the tip flap, provided stalling of the root region is artificially induced before the angle of attack exceeds the value necessary to cause local separation at the tips.

The above modifications are common to any wing having spoiler type controls. Associated with the jet spoiler, however, we have a weight penalty ΔW, and a maximum power requirement HP_{max}. We assume that the spoiler momentum coefficient C_{μ_s} has a maximum value $C_{\mu_{sm}}$ which is dictated by the C_{l_p}, the coefficient of damping in roll, and the required $\left(\frac{Pb}{2V}\right)_{max}$, the maximum wing tip helix angle in steady roll. For aircraft in the VTOL and STOL class, the momentum flux itself may give an important contribution to the rolling moment at low forward flight speeds, and would hence influence the value of $C_{\mu_{sm}}$. If, for this spoiler configuration, the flow issues from an upper surface slot having length l_s and width δ_s, the C_μ for any jet spoiler slot having length l and width δ is given by

$$C_{\mu_s} = C_{\mu S}\ \frac{\delta}{\delta_s}$$

where $C_{\mu_{\delta_s}} = \dfrac{\rho_s V_s^2 \delta_s}{\frac{1}{2}\rho_o V_o^2 \bar{c}}$, and $\bar{c}$ is a mean chord over the portion of the wing covered by the spoiler (see Figure 3). We have assumed the slot velocity to be dependent only upon the reservoir pressure of the jet system, an assumption valid only for large contraction ratios in the jet system. The possibility of using C_{μ_M} for boundary layer control will depend upon the merit of a system which will control air to the BLC slot and the spoiler slot in such a way that the volume flow rates to the spoiler and the boundary layer control jet are co-ordinated in a way commensurate with the desired handling qualities. Since flight at low velocities, especially during landing, is hazardous if the use of flight controls affects the net lift of the wing, it would be most desirable to utilize the BLC portion of the wing to counter the lift loss associated with the spoiler. One possible system (Fig. 4), would involve increasing the BLC and spoiler jet volume flow rates simultaneously in such a way that $\Delta C_{L_S} = \Delta C_{L_{BLC}}$ for any C_{μ_S}. This approach involves power penalties greater than that required by the spoiler alone. If BLC is operated continuously at a level $C_{\mu_{BLC_o}}$, then the total $C_{\mu_{max}}$ is given by

$$C_{\mu_{TOTAL\,max}} = C_{\mu_{BLC_o}} + K C_{\mu_{max}} \frac{\delta}{\delta_s}$$

where K is related to the functional dependence of $\Delta C_{L_{BLC}}$, the lift increment associated with increase in boundary layer air flowing above the level $C_{\mu_{BLC_o}}$, upon ΔC_{L_S}, the lift decrement due to the spoiler, in order that the net change in lift be zero. Since the differential BLC blowing may contribute appreciable rolling moment in special cases, this system may allow reduction of $C_{\mu s_{max}}$.

The above arguments suggest that the major advantage of the air jet spoiler, as compared to the use of conventional spoiler designs on high lift aircraft, comes from its use in conjunction with other high lift devices involving blowing or suction, and secondarily from the indications that its control response is more favorable. With this in mind some preliminary calculations on the L-21 aircraft are carried out below for power requirements, weight penalties, trim changes, and performance of a BLC-blowing-jet spoiler combination.

III. Calculations for L-21 Airplane

Dimensions and orthographic projections of this aircraft are given in Figure 5. From this drawing the following data is obtained:

$AR = 6.92$

$b = 35.2$ ft.

$S = 178.5$ sq. ft.

$c = 63$ inches (mean aerodynamic chord)

$c_f = .234$ (flap and aileron)

$W = 1700$ lbs. (2 people and maximum fuel load)

a. Effect of full span flaps on the maximum lift coefficient

From Reference 6, the section lift slope of the USA 35-B is given as .099 per degree. It is assumed, in the absence of any experimental data, that the lift slope of the modified 35-B airfoil (upper ordinates increased 4%) is also .099. The lift slope of the L-21 wing is then given by

$$a_w = (.9875)\frac{(.099)}{1+\frac{(57.3)(.099)}{\pi(6.92)}} = .0775 \quad \text{(flap undeflected)}$$

We are considering landing speeds in the vicinity of 50 fps, and therefore examine the $C_{L_{max}}$ at a Reynolds Number of about 1.66×10^6 based on wing chord. From Reference 2, aerodynamic data taken at a Reynolds number of 1×10^6 indicate that root stalling will begin at an angle of attack of 16°, and that $\alpha_{0L_{\delta_f=0}}$, the angle of zero lift, flaps undeflected, is -4°, yielding a maximum lift coefficient of 1.55, for power-off flight.

The following table gives typical section lift increments for slotted flaps deflected 40°:

ΔC_L	Reference	$c_f/\bar{c}$
1.56	11	.2566
1.40	8	.20
1.33	1	.25c
1.35	1	.30c

A value of 1.30 is used here as typical for a slotted flap having c_f/c = .254. The change in α_{oL} for the L-21 wing having a slotted flap extending from .09-b/2 to .875-b/2 is given by (Reference 8).

$$\Delta\alpha_{oL} = -(8.35)\ (1.3) = -10.86$$

The increment in lift coefficient due to the flap deflection is .842. In Reference 2 the stalling angle was found to decrease about 2° for a partial span with flaps deflected 40°. If a value of -3° is used for full span flaps, the maximum lift coefficient becomes

$$\Delta C_{L_{max}\ \delta_f = 40°}\ \text{(full span)} = (27.86)\ (.0775) = 2.16$$

and the net increase in $C_{L_{max}}$ is .61.

b. <u>Effect of boundary layer blowing over inboard flap</u>

The variation in $\Delta C_{L_{BLC}}$ (due to BLC over a plain flap) vs. $C_{\mu_{BLC}}$ for δ_f = 40° is given in Figure 7. The $C_{\mu_{BLC}}$ for which the inboard flap contribution takes on its theoretical value was obtained from the correlated data presented in Reference 4. The section lift increment at the inboard flap is then increased by .98, causing the $\alpha_{o.L.}$ of the wing to shift -3.43°. The variation of $\Delta C_{L_{BLC}}$ with $C_{\mu_{BLC}}$ is taken to be linear up to $C_{\mu_{BLC}}$ = .03 (this is accurate in most instances for $\delta_f < 40°$, and is assumed to be valid here). For $C_{\mu_{BLC}} > .03$, $\Delta C_{L_{BLC}}$ continues to increase, due to "chord extension", but at a much slower rate. A probable variation is indicated by the dashed line. It is assumed that the system described here will be operated at a $C_{\mu_{BLC}}$ less than .03. The stalling angle of attack of 13° for BLC off is retained for BLC on, although the validity of this assumption will depend upon the stalling characteristics of the particular section under consideration.

From the studies of the maximum lift coefficient of light planes with BLC equipment given in Reference 5, it appears that

$$\frac{C_{L_{max}}\ \text{(power on)}}{C_{L_{max}}\ \text{(power off)}} = 1.6 \text{ for the range of flap deflections}$$

under consideration. The effect of power is then to suppress separation of the inboard wing panel, as is shown in Figure 6. Due to the lower power loading of the L-21, as compared with that of Reference 5, the power effect is estimated at 1.3, giving a maximum lift coefficient of 3.16 with $\delta_f = 40°$, $C_{\mu_{BLC_c}} = .03$.

c. Power considerations

As the spoiler jet and blowing flap are fed by the same power source, the power requirements will be based upon the maximum flow that might be required during normal flight. We assume a design $\frac{Pb}{2V}$ of .07. Reference 10 gives the C_{l_p} of the L-21 as .53, which demands a $C_{\mu_{S_{max}}}$ of .135. Since it is desirable to have the net lift of the wing remain constant with application of the spoiler, the following system will be adopted:

(1) BLC operates continuously at a level $C_{\mu_{BLC_o}}$

(2) Variable width jets are used to vary C_μ for jet and blowing flaps, and

(3) The net lift is unchanged with application of a spoiler jet; that is, right wing spoiling is accompanied by increase in $C_{\mu_{BLC}}$ on left wings.

Considering the last specification, we have, for two flap panels, $\Delta C_{L_{BLC}} = 8.87$ $\Delta C_{\mu_{BLC}}$ as a result of the linear variation assumed. Also

$$\Delta C_{L_S} = \frac{-(4)C_l}{(.9)} = \frac{-(4)(.275)}{(.9)} C_{\mu_s} = -1.222\, C_{\mu_s}$$

The $C_{\mu_{BLC\,max}}$ required to satisfy condition (3) above is therefore given by:

$$C_{\mu_{BLC_{max}}} = C_{\mu_{BLC_o}} + \frac{(1.222)C_{\mu_{s\,max}}}{8.87} = C_{\mu_{BLC_o}} + .138 C_{\mu_{s\,max}}$$

A force of $1/2\, \Delta C_{L_{BLC}} S_w q_o$ will act at a moment arm roughly 1/4 that of the spoiler, so that 1/4 of the contribution to C_l will come from the flap. Hence

$$C_{l_{max}} = \frac{(.275)}{(.8)} C_{\mu_{s\,max}} = .0371 \quad \text{and for} \quad \left(\frac{Pb}{2V}\right)_{max} = .07$$

$$C_{\mu_{s\,max}} = .108$$

$$C_{\mu_{BLC_{max}}} = C_{\mu_{BLC_o}} + .015$$

We let $C_{\mu_{BLC\,max}} = .015$ (halving the former contribution of BLC to the angle of zero lift) so that

$$C_{\mu_{BLC\,max}} = .030$$

When dealing with power requirements, a volume flow coefficient is useful, defined by

$$C_Q = \frac{Q}{V_o S}$$, S is the affected wing area

We find that

$$C_{Q_{BLC}} = C_{\mu_{BLC}} \frac{V_o}{V_{BLC}}$$

$$C_{Q_s} = C_{\mu_s} \frac{V_o}{V_s}$$

The total volume flow required is given by C_{QT} :

$$C_{QT} = \frac{Q_{TOTAL}}{V_o S_w} = \frac{V_\infty}{S_w}\left\{ C_{\mu_{BLC}} \frac{\ell_{BLC}}{V_{BLC}} + C_{\mu_S} \frac{\ell_S}{V_S} \right\}$$

$$Q_{TOTAL} = V_o^2 c \left\{ C_{\mu_{BLC}} \frac{\ell_{BLC}}{V_{BLC}} + C_{\mu_S} \frac{\ell_S}{V_S} \right\} ft^3/sec$$

We assume that $V_{BLC} = V_S = C\sqrt{\Delta P}$, where C is a constant dependent on slot design and assumed the same for both slots, and ΔP is the pressure differential across the slots assumed to be the same for spoiler and flap. The required volume flow is given by

$$Q_{TOTAL\ REQD} = \frac{V_o^2 c b}{C\sqrt{\Delta P}}\left[(.109)(.0425) + (.03)(.289)\right] = \frac{.0133\, V_o^2 c b}{C\sqrt{\Delta P}}$$

Now, $V_o^2 = 841 \dfrac{W}{S_w C_L}$ $ft^2/sec.$, and for a design $C_{L_{max}}$ of 2.98 (now using the reduced value of $\Delta C_{L_{BLC_o}}$)

$$Q_{TOTAL\ REQD} = \frac{.0133\, c b}{S_w (2.98)} (841) \frac{W}{C\sqrt{\Delta P}} = 3.52 \frac{W}{C\sqrt{\Delta P}}\ ft^3/sec$$

The air horsepower required to carry this volume of air through the pressure differential ΔP is $\dfrac{\Delta P\, Q_{TOTAL}}{550}$ $= \dfrac{.0064}{C}\sqrt{\Delta P}\ W\ HP$

As a power supply, the hydraulic system described in Reference 5 will be used in the calculation of required flow quantity and duct pressure. This system utilizes a high efficiency hydraulic pump and axial flow fans capable of 8.5 air horsepower. The probable weight penalty when installed on the L-21, including structual modification, is approximately 300 lbs. A possible reduction of full throttle power of 15% can be expected. Taking minimum volume flow of 40 $ft^3/sec.$ (corresponding to slot widths of .004c) and C = 30 $ft^2/sec.\ lb.^{1/2}$.

$$\Delta P = \left\{ \frac{(352)(2000)}{(30)(40)} \right\}^2$$

$$\Delta P = 34.6 \ lb/ft^2$$

The air horsepower required is 2.51, well within that available after internal losses.

Assuming BLC is off, and that 5 air horsepower are available, the maximum $\rho b/2v$ that can be developed at any airspeed, V_O, will be calculated. Here a $C_{\mu c\, max}$ of 1.35 is needed, so that

$$Q_{TOTAL\ REQ'D} = \frac{.00574\ V_o^2 cb}{C\sqrt{\Delta P}} = \frac{.961\ V_o^2}{C\sqrt{\Delta P}} = \frac{\text{Air Horsepower} \times 550}{(\Delta P)}$$

If a maximum volume flow of 40 ft^3/sec is allowed,

$$\Delta P_{max} = 68.8 \ lbs./ft^2$$

and the maximum V_O for which a $\rho b/2v$ of .07 can be developed is

$$\left[\frac{(40)\ (20)\ (68.8)^{1/2}}{.961} \right]^{1/2} = 103 \text{ fps}$$

For $V_O > 103$ fps, $\left(\frac{Pb}{2V}\right)_{max} = \frac{743}{V_O^2}$. These results are given in Figure 8.

d. <u>Longitudinal trim</u>

From Reference 8, the conditions for longitudinal trim require that

$$\Delta C_{M_{ac}} + \Delta C_L \frac{X_a}{c} - a_t\left(\Delta i_t + \tau \Delta\delta_e - \Delta\epsilon\right)\bar{V}\eta_t = 0$$

Assuming $C_{\mu_{BLC_o}}$ = .03, C_{μ_s} = 0, δ_f = 40° (full span).

$\Delta C_{M_{ac}}$ = -.57

ΔC_L = 1.11 (power off)

X_{ac} = .25

η_t = .8 (assumed)

$\bar{V}$ = .566

a_t = .069 approximately

τ = .34

Therefore 1.11 Xcg - [illegible] - .0202 ($\Delta i_t + .34\delta_e - \Delta\epsilon$) = 0

Now $\frac{d\epsilon}{dC_L}$ = 5.72 away from ground effect, and we assume $\frac{d\epsilon}{dC_L}$ = 2.86 during landing. The control deflections required during landing to overcome the moments associated with the flap, and BLC are then

$$\Delta i_t + .34\delta_e = 50.45\, X_{cg} - 26.64$$

Placing the cg at 30%c (Ref. 5),

$$\Delta i_t - .34\,\delta_e = -11.50$$

which defines the maximum control deflections over and above that required by the unmodified aircraft (δ_f = 0°) during landing.

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COMPARISON OF ROLLING MOMENT COEFFICIENT AS A FUNCTION OF CONTROL DISPLACEMENT FOR SPOILER SLOT

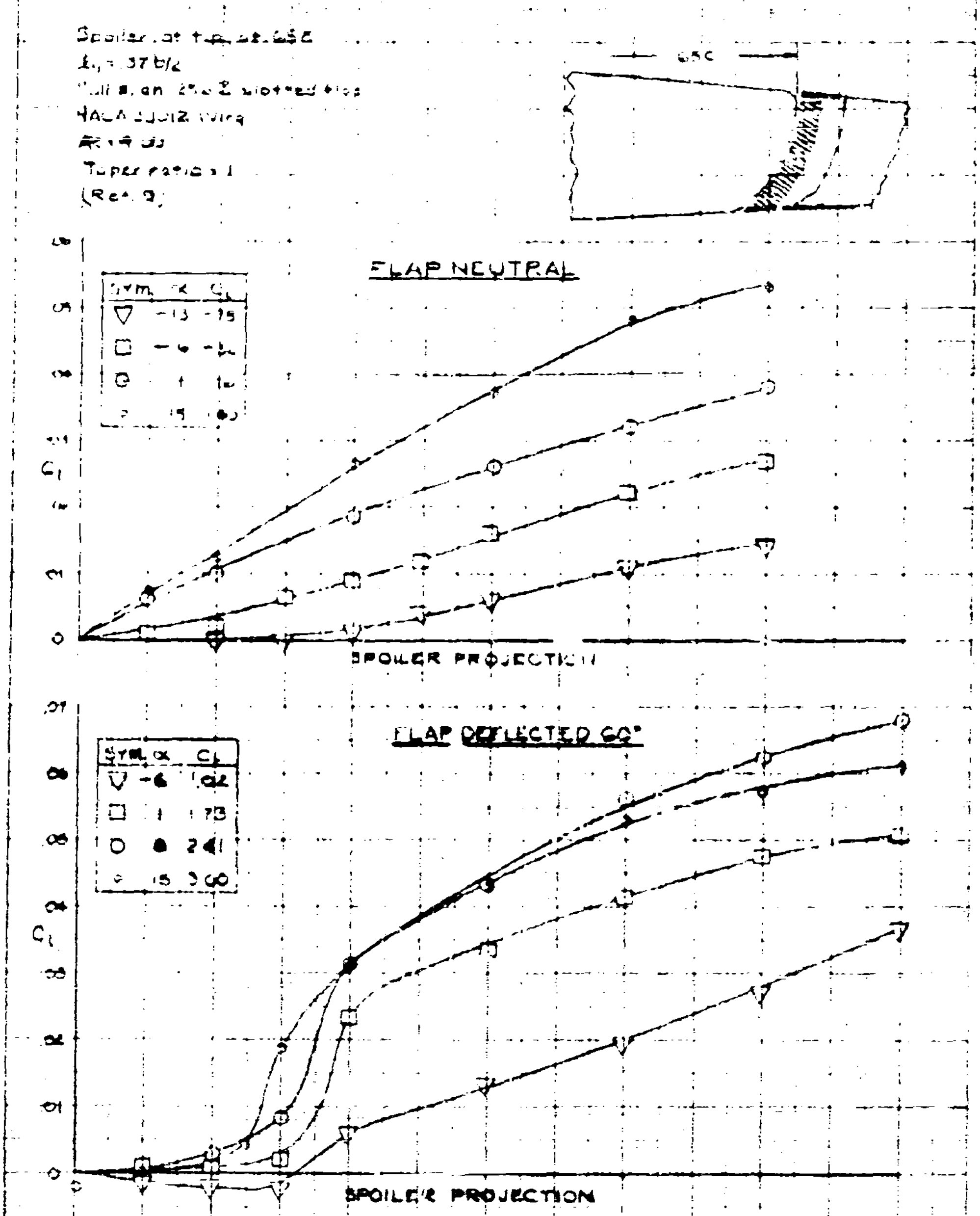
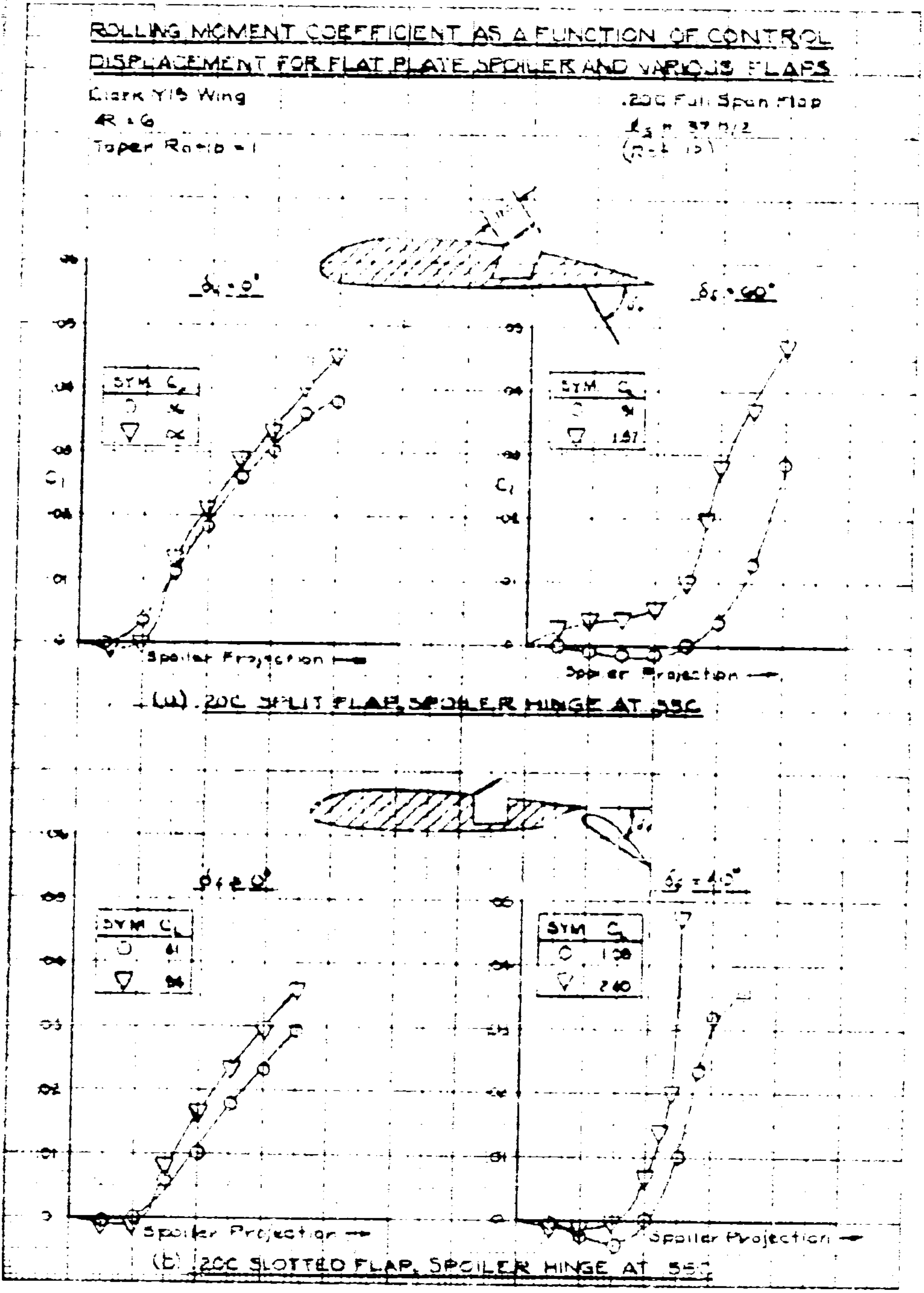


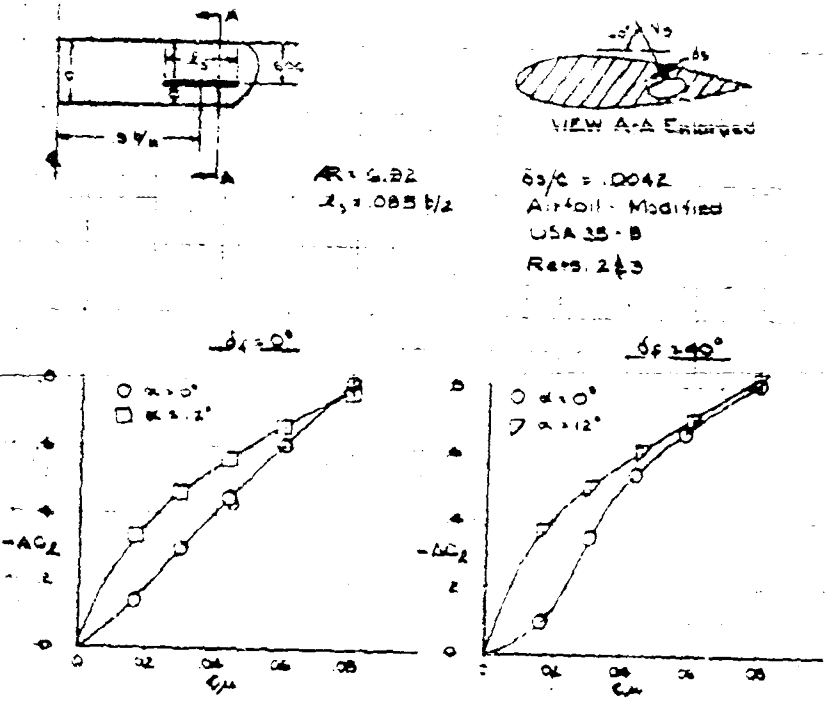
FIG. 1



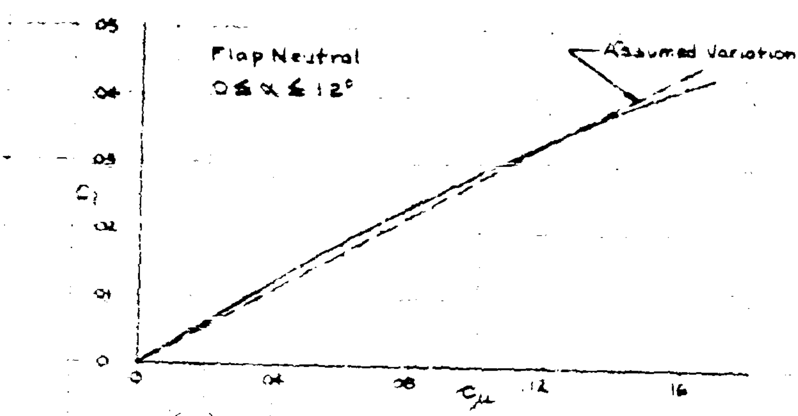
ROLLING MOMENT COEFFICIENT AS A FUNCTION OF CONTROL DISPLACEMENT FOR FLAT PLATE SPOILER AND VARIOUS FLAPS
Clark Y15 Wing
AR = 6
Taper Ratio = 1
.20C Full Span Flap
SYM C_L
C_l
Spoiler Projection
(a) .20C SPLIT FLAP, SPOILER HINGE AT .55C
Spoiler Projection
(b) .20C SLOTTED FLAP, SPOILER HINGE AT .55C

FIG. 2

AIR JET SPOILER



(A) TWO-DIMENSIONAL SPOILER



(B) SPOILER FOR LATERAL CONTROL

FIG 3

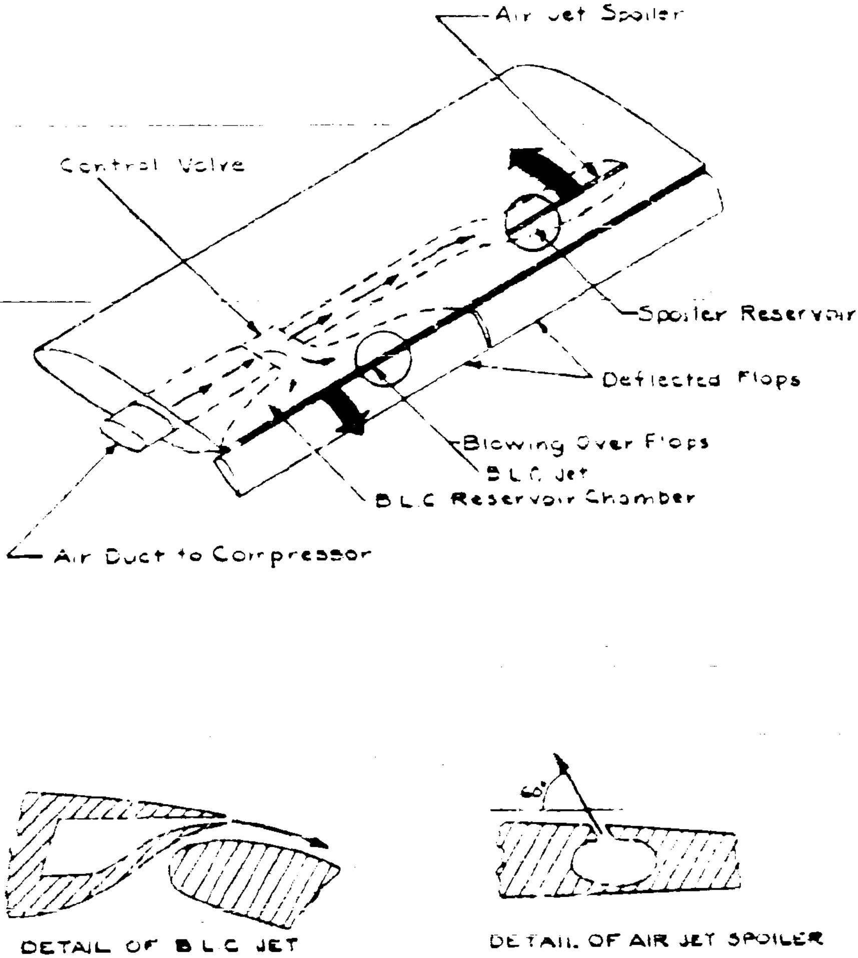
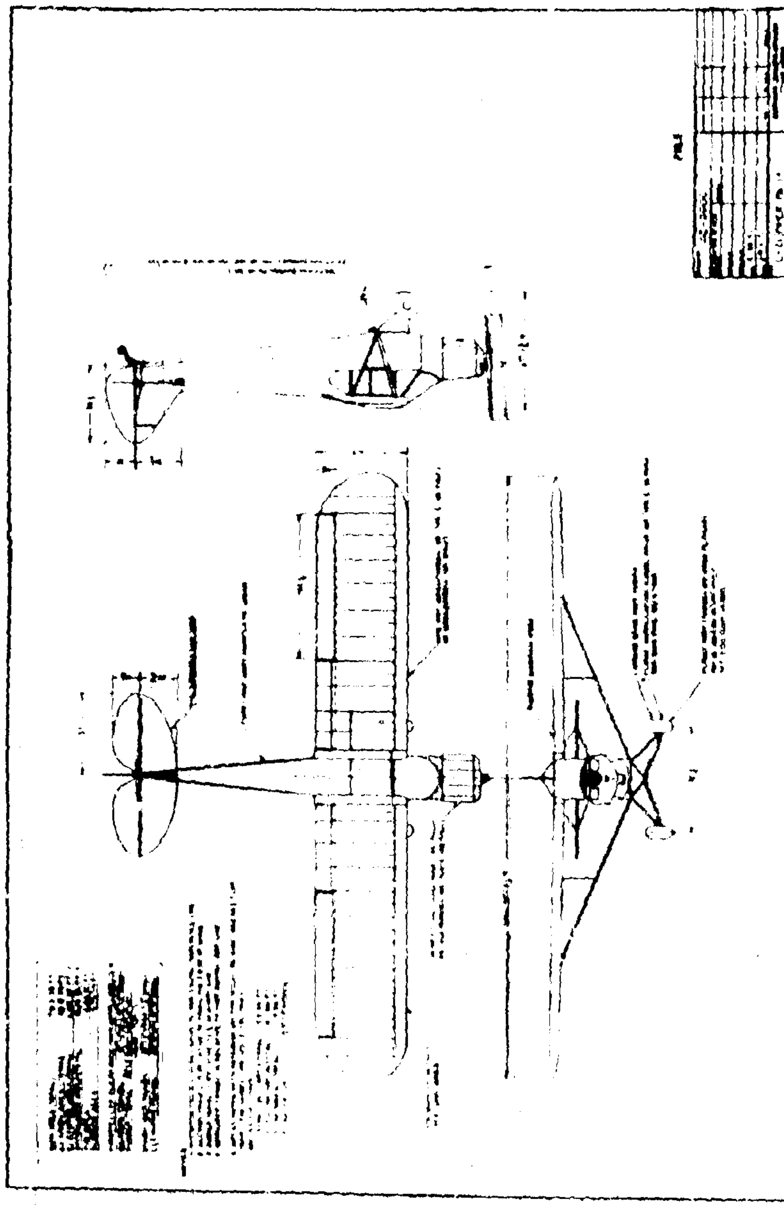

Air Jet Spoiler
Control Valve
Spoiler Reservoir
Deflected Flaps
Blowing Over Flaps
B.L.C. Jet
B.L.C. Reservoir Chamber
Air Duct to Compressor
60°
DETAIL OF B.L.C. JET
DETAIL OF AIR JET SPOILER

FIG. 4



CALCULATED EFFECT OF MODIFICATION UPON C_L VS. α

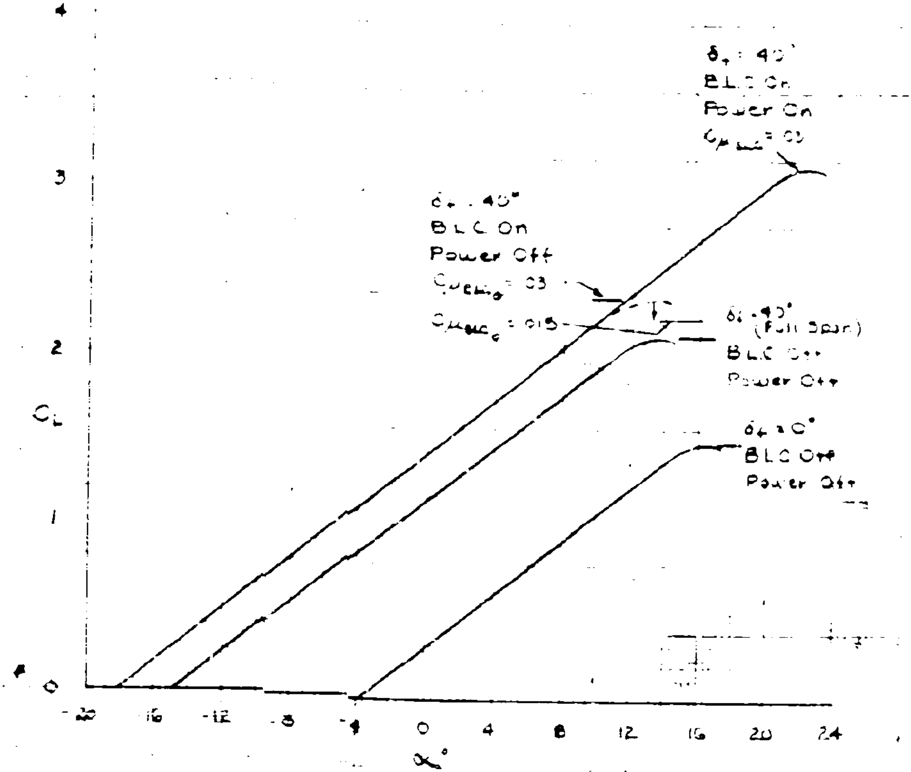
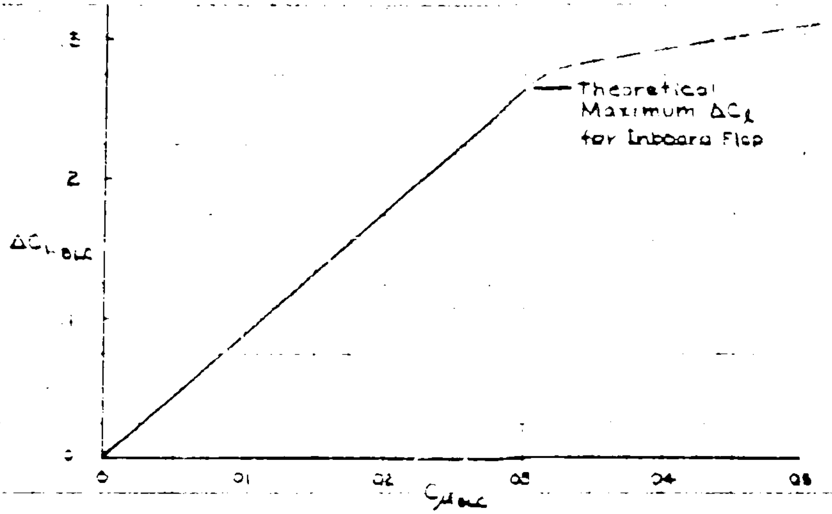
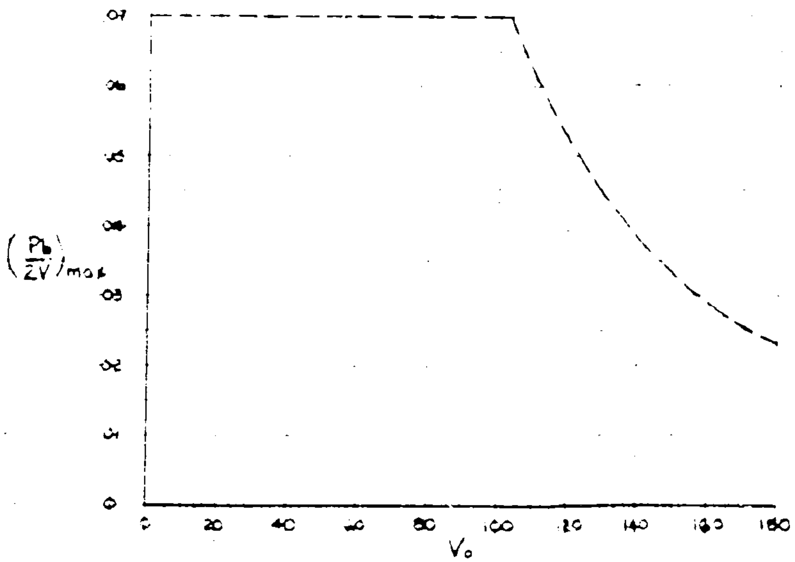


FIG. 6



ASSUMED VARIATION OF $\Delta C_{L_{BLC}}$ WITH C_μ
FOR BLOWING OVER INBOARD FLAP
FIG. 7



POSSIBLE ROLL RATE, B.L.C. OFF,
$\left(\frac{Pb}{2V}\right)_{max}$ = .07, AIR HORSEPOWER = 5, $Q_{TOTAL\ REQD}$ = 40 ft^3/sec

FIG. 8

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